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Effects of simulated acid rain on root growth of *Cunninghamia lanceolata* and *Schima superba* saplings planted in acidified soil

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Abstract—Results from pot culture (with one-year old *Cunninghamia lanceolata* and *Schima superba*) are described. It was found that the biomass production and elongation of *C. lanceolata* was seriously inhibited at pH 2.0 rain, but for *S. superba*, was not affected markedly. When pH values of experimental rain were higher than 2.0, the root growth of both species was not adversely affected. Aluminium had already accumulated to some degrees in the roots of both trees, and started to affect the root growth of *C. lanceolata* at pH 2.0 rain. The soil chemistry was also examined. Increased acidity of experimental rain increased the leaching of Ca and Mg. The Al/Ca mol ratio increased from 0.3 to 0.9 in top soil, and in rhizosphere to 1.5 when the pH values of simulated acid rain were 4.5 to 2.0. In this experiment, NO_3^- fertilization effect was discovered.

Keywords: simulated acid rain; soil acidification; *Cunninghamia lanceolata; Schima superba*; root biomass.

INTRODUCTION

In some recent papers, it has been suggested that acid precipitation mobilizes Al to some extent that forest trees are damaged. Ulrich *et al.* (Ulrich, 1980) observed in Solling area of Germany that Al concentration in the podzolic soil solution increased from 0.3—0.95 mg/L, in April of 1969 to values between 1.1 and 1.8 mg/L in November. Simultaneously the biomass of fine roots decreased from 2500 kg/ha in May to 200 kg/ha in August. On this basis they concluded that "Aluminium concentration of 1 to 2 mg/L, as now existing continuously, should therefore damage root systems of the trees especially in period when nitrification is favored".

Ulrich also emphasized the importance of the interaction between Al and Ca in soil. He assumed that Al injury is likely when the mol ratio of Ca/Al in the equilibrium soil solution is 1.0 or lower, and when the mol ratio of Ca/Al is lower than 0.2, Al toxicity even leads to tree death.

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Liu Houtian *et al.* (Liu, 1988) introduced the above opinion as the evidence to explain the declining *Pinus massoniana* forest in Nanan district of Chongqing City, Sichuan Province, and assumed that the forest dieback was caused by Al toxicity. About the same event, Chen Chuying *et al.* (Chen, 1988) considered that acidic precipitation damage the tree leaves and impair their ability to photosynthesize, and decrease the tree vigor so that the periodical insect pests especially the borer insects occur. As a result, the trees are made lethal.

In recent years, Chinese researches were mainly concentrated on above-ground of trees, less research was done about the underground, and how much role does the mobilized Al in acidified soil play in forest dieback in acid rain areas of China. Even if possible, what is the critical value for the concentration of Al, or the mol ratio of Al/Ca? And is it possible that the trees continuously exposed to artificial acid rain are lethal when soil acidity already lower than pH 4.0? The authors will give some preliminary answers to these questions at the end of the simulated experiments.

MATERIALS AND METHODS

This experiment was carried out by pot culture in Huitong Research Station of Forest Ecosystem, Hunan Province where there is no acid rain pollution. The pot size is 33 cm in diameter and 30 cm high with about 7.0 kilos soil in each. The soil is yellow red mountainous soil and acidified by means of diluted heavy sulphate to different acidity. Natural soil which pH level is approximately 6.0 was arranged as controlled experiment. After the pot soil was naturally dried, one-year old saplings of *C. lanceolate* and *S. Superba* were planted.

After the saplings rejuvenated, they were exposed to different "rain" of pH level which are 6.5 (natural water), 4.5, 3.0, 2.0 and the addition of acid is a mixture of H_2SO_4: HNO_3 (8:1). Each treatment has ten replicates, then the total replicates amount to 2× 4×10. The duration exposure to simulated acid rain was from April 30 to October 1, 1989. It "rains" for 20 minutes once every day at 7:30 in the morning or at 7:00 in the evening except the natural rain days. In this period, the simulated acidic precipitation was equal to 810 mm.

Just after saplings stop growing, the basal diameter and height were measured. The leaf, stem and root biomasses were investigated according to different species. Especially, the root investigation was done by three size classes which are big, intermediate and fine.

The chemical analysis of soil and sapling root are as described by a Handbood of Soil Chemical Analysis (Institute of Soil Science, 1978). Ca and Mg in the soil extracted by 1 mol NH_4Ac at pH 7.0 and subsequently measured by Plasma 100. Al in the soil was extracted by 1 mol/L KCl and titrated by NaOH solution. Soil pH was measured in a soil/water or soil/1 mol/L KCl solution of 1:2. Ca, Mn and Al in the plant root were measured as follows: the plant roots were reduced into ashes at 550°C, and subsequently dissolved in hot solution of 20% HNO_3, then measured by Plasma 100.

RESULTS AND DISCUSSIONS

Table 1 shows the Ca and Mg contents in different soil layers exposed to different acidity of artificial rain. Following the decrease in pH value of simulated acid rain, the Ca and Mg concentrations in top soil were reduced markedly, from 170.7 and 29.1 mg per 100g dry soil of control experiment respectively to 5.5 and 2.3 mg per 100g dry soil at pH 2.0, and in the rhizosphere soil, the Ca and Mg contents declined from 192.9 and 28.4 mg per 100g dry soil of control experiment respectively to 12.8 and 2.7mg per 100g dry soil at pH 2.0. The difference between different treatments in Ca and Mg contents of top soil was greater than that of rhizosphere soil. These results confirmed that increased acidity of the artificial rain obviously increased the leaching of Ca and Mg, and that Ca and Mg in top soil were more readily leached than in rhizosphere soil. The chemical analyses of percolation solutions received from under

Table 1 Ca and Mg contents in soils exposed to different pH level of acid rain, mg/100g dry soil

Sampling position	Simulated acid rain pH	Ca	Mg
	2.0	12.8	2.7
Rhizosphere soil	3.0	65.5	8.3
	4.5	96.9	14.8
	6.5 (natural water)	192.9	28.4
	2.0	5.5	2.3
	3.0	37.4	5.4
Top soil	4.5	93.7	15.0
	6.5 (natural water)	170.7	29.1

Table 2 Comparison of contents of mineral elements and main anions in percolation solutions when applied to artificial precipitation, mg/L

Simulated acid rain, pH	Percolation solution, pH	K	Na	Ca	Mg	Al	Fe	Cu	Zn	Mn
Contrast (6.5)	6.44	1.7	1.3	12.5	3.3	3.0	3.1	0.02	3.5	0.03
4.5	6.17	1.1	1.9	17.2	4.8	1.3	1.2	0.02	1.0	0.01
3.0	5.30	1.7	2.0	20.2	5.3	2.3	1.6	0.01	0.6	0.03
2.0	3.25	7.8	4.3	60.1	34.1	12.0	0.8	1.30	0.4	3.68

Simulated acid rain, pH	Percolation solution, pH	Cl^-	NO_3^-	SO_4^{2-}
Contrast(6.5)	6.44	1.2	13.5	29.0
4.5	6.17	0.4	–	55.7
3.0	5.30	0.3	3.3	74.8
2.0	3.25	1.2	56.2	706.8

culture pots exposed to different acidity of artificial rain give further evidence that Ca and Mg in soils have already seriously leached by the acidic precipitation (Table 2). Ca and Mg concentrations in the leachates increase from 12.51 and 3.32 mg/L received natural water to 60 and 34 mg/L received "rain" of pH 2.0. Table 2 also demonstrates the leaching of other elements. The loss of these base cations may eventually lead to the accumulated acidification of soil (Yu, 1987).

As a result of soil acidification, certain toxic element of aluminium are activated and released into soil. The content of exchangeable aluminium increased from nil to 0.9 mmol per 100g dry soil in parallel to the decline of soil acidity (Table 3). The content of exchangeable Al in top soil was less than that in rhizosphere soil. Base saturations are also given in Table 3. The base saturation in top soil and rhizosphere soil exposed to pH 2.0 simulated acid rain decreased by 65.7% and 47.5% compared with contrast treatment.

Table 3 Content of exchangeable aluminium in soil exposed to simulated acid rain, mmol/100g dry soil

Sampling position	Simulated acid rain, pH	Soil pH		Al	Ca	Mg	Base saturation, %
		H_2O	KCl				
Top soil	2.0	3.26	2.96	0.91	0.22	0.05	17.2
	3.0	3.95	3.16	0.79	0.86	0.06	33.1
	4.5	4.77	3.98	0.26	1.77	0.32	51.9
	contrast(6.5)	6.12	5.05	0	12.51	0.80	82.9
Rhizosphere soil	2.0	3.69	3.20	1.50	0.10	0.03	27.1
	3.0	3.81	3.33	1.00	0.59	0.04	29.9
	4.5	4.75	3.92	0.30	1.33	0.30	51.5
	contrast(6.5)	5.76	4.75	0	2.40	0.64	74.7

Table 4 demonstrates the root biomass of *G. lanceolata* and *S. superba* grew in acidified soil. The total biomass of both trees had a little increase when applied to less acidic precipitation than pH 2.0, but at pH 2.0, the total biomass of *C. lanceolata* had statistical difference by T-test compared with the control experiment, and for *S. superba*, decrease in the total biomass was not obviously by T-test. The biomass of root of both big and intermediate size had the same trend as the total biomass. For *C. lanceolata*, the growth of fine root, the least size in the three classes, was inhibited by simulated acid rian and soil acidification. The fine root biomass started to decline at pH 3.0 "rain". At pH 2.0 rain, the biomass was reduced pronouncedly, but for *S. superba*, the biomass of fine root was not adversely affected.

Root length is one of important determinators which stands for the absorption function, so researches on root length affected by acid rain have practical meaning (Beijing Forestry College, 1981). Table 5 lists the root length of *C. lanceolata* and *S. superba* under different acidic treatments. For *C. lanceolata*, the root length of big and ntermediate classes had the same trend to increase, when applied less acidic precipitation than 2.0. At pH 2.0, the root elongation was inhibited. The elongation of fine root was inhibited when received simulated acid rain of pH 2.0, and the fine root length was only 19% of that under control experiment. And for *S. superba*, the elongation of fine root was not adversely affected.

Table 4 Effects of simulated acid rain and soil acidification on root biomass of *C. lanceolata* and *S. superba*, g/sapling

Species	Simulated	Soil	pH				
	acid rain, pH	H_2O	KCl	Big[1]	Middle[2]	Fine[3]	Total
C. lan-	contrast (6.5)	5.91	4.52	0.94	0.94	1.71	3.59
ceolata	4.5	5.12	4.14	1.29	0.88	3.54	5.71
	3.0	3.65	3.69	4.21	1.68	2.69	8.58
	2.0	3.35	3.04	0.49	0.16	0.32	0.97
	contrast (6.5)	5.76	4.75	3.20	0.19	0.38	3.77
S. superba	4.5	4.75	3.92	4.10	0.34	1.37	5.81
	3.0	3.81	3.33	4.64	0.58	2.32	7.54
	2.0	3.69	3.20	1.83	0.18	0.61	2.62

Note: 1. C. >1mm, S.>0.7mm
2. 0.5—1mm, S. 0.2—0.7mm
3. C. <0.5mm, S. <0.2mm

Table 5 Effects of simulated acid rain and soil acidification on root elongation of *C. lanceolata* and *S. superba*, cm/sapling

Species	Simulated	Soil	pH	Big	Middle	Fine
	acid rain, pH	H_2O	KCl	Length	Length	Length
	Contrast (6.5)	5.91	4.52	167.6	363.5	1405.1
				(100)	(100)	(100)
C. lan-	4.5	5.12	4.14	230.7	340.3	2908.7
ceolata				(137)	(94)	(207)
				(448)	(179)	(157)
	2.0	3.35	3.04	87.4	61.9	262.9
				(52)	(17)	(19)
	Contrast (6.5)	5.76	4.75	308.2	341.8	1999.6
				(100)	(100)	(100)
S.superba	4.5	4.75	3.92	395.5	621.4	7270.3
				(128)	(182)	(364)
	3.0	3.81	3.33	447.4	1054.6	12338.2
				(145)	(309)	(617)
	2.0	3.69	3.20	176.7	333.6	3252.8
				(57)	(98)	(163)

Note: Number in the parenthesis is percentage compared with contrast

Plant root systems absorb nutrients and moisture which are needed to photosynthesize from soil. Once the root systems injured, its physiological absorption function is impaired, subsequently the amount of photosynthetic products tends to decrease, so the biomass of plant is reduced (Foy, 1971). Table 6 shows the biomass of *C. lanceolata* and *S. superba* under different treatments. When soil pH was lower than 4.0 and pH of simulated acid rain greater than 3.0, the biomass of both *C. lanceolata* and *S. superba* was not adversely affected, in the other way, tended to increase because of fertilization effect of NO_3^- in the "rain". When soil pH lower than 4.0 but pH value of artificial rain was 2.0, biomass production of *C. lanceolata* was reduced obviously, but for *S. superba*, the biomass production just started to decline.

Table 6 Effects of simulated acid rain and soil acidification on biomass production of *C. lanceolata and S. superba*, g/sapling

Species	Simulated acid rain, pH	Soil pH H_2O	Soil pH KCl	Leaf	Stem	Root	Total
C. lanceolata	contrast (6.5)	5.91	4.52	4.40	2.02	3.60	10.02
	4.5	5.12	4.14	5.80	2.73	5.71	14.24
	3.0	3.65	3.69	9.08	3.89	8.58	21.55
	2.0	3.35	3.04	0.63	1.10	0.97	2.70
S. superba	contrast (6.5)	5.76	4.75	1.73	1.83	3.76	7.32
	4.5	4.75	3.92	3.67	3.01	5.81	12.49
	3.0	3.81	3.33	7.24	6.19	7.54	20.97
	2.0	3.69	3.20	3.96	2.90	2.63	9.49

After active aluminium enters into soil, and in the meantime, the Al/Ca mol ratio attains up to a certain value, aluminium toxicity to plant root may take place. The results of simulated experiments are summarized in Table 7. For *C. lanceolata*, when the Al/Ca mol ratio increased from nil to 0.47, the root biomass production was not inhibited, but when the Al/Ca mol ratio rose up to around 5.0, both the total biomass and fine root biomass were reduced markedly

Table 7 Relationship between the soil Al/Ca mol ratio and root biomass of *C. lanceolata* and *S. superba*

Species	Simulated acid rain, pH	Soil pH H_2O	Soil pH KCl	Exchangeable Al, mmol/100g	Exchangeable Ca, mmol/100g	Al/Ca	Root biomass, g/sapling
C. lanceolata	Contrast(6.5)	5.91	4.52	0	4.55	0	3.60
	4.5	5.12	4.14	0.30	2.38	0.13	5.71
	3.0	3.65	3.69	0.61	1.29	0.47	8.58
	2.0	3.35	3.04	1.12	0.23	4.89	0.97
S. superba	contrast (6.5)	5.76	4.75	0	2.40	0	3.76
	4.5	4.75	3.92	0.30	1.33	0.20	5.81
	3.0	3.81	3.33	1.00	0.59	1.70	7.54
	2.0	3.69	3.20	1.50	0.10	15.80	2.63

compared with the control experiment. And for *S.superba* when the soil Al/Ca mol ratio mounted from 0.2 to 15.8, the root biomass production was not harmfully affected prominently. It is important that during the root investigation no root death was found.

Abrahamsen considered that certain tree species have the ability to translocated Al from the roots to other parts of the plants (Abrahamsen, 1983). In this way extreme concentrations of Al in the roots may be avoided, so aluminium may not be toxic to the root systems. Resistance to Al toxicity may differ from species to species. In the simulated experiments, for *C. lanceolata*, when the root Al/Ca mol ratio increased from 2.1 to 2.9, the root biomass was not adversely affected, but when up to 4.9, the root biomass was reduced markedly. But for *S. superba*, when the root Al/Ca mol ratio rose from 1.2 to 2.6, the root biomass was not obviously affected (Table 8).

Table 8 Relationship between Ca and Al contents and Al/Ca mol ratio in the roots and root biomass of *C. lanceolata* and *S.superba*

Species	Simulated acid rain, pH	Soil pH		Ca,	Al,	Al/Ca	Root biomass, g/sapling
		H_2O	KCl	mmol/100g			
	Contrast(6.5)	5.91	4.52	9.17	18.99	2.1	3.60
C. lanceolata	4.5	5.12	4.14	7.52	19.92	2.7	5.71
	3.0	3.65	3.69	6.76	19.41	2.9	8.58
	2.0	3.35	3.04	4.21	20.61	4.9	0.97
	contrast (6.5)	5.76	4.75	7.39	9.14	1.2	3.62
S. superba	4.5	4.75	3.92	6.24	9.78	1.6	5.81
	3.0	3.81	3.33	5.23	11.03	2.1	7.54
	2.0	3.69	3.20	5.29	13.87	2.6	2.63

In considering the factors affecting the root growth, neither aluminium toxicity nor soil acidification is the sole mechanism to injury the roots. The combined stress of them as well as the accumulated stress of acidic precipitation must be take into account (Boris, 1985). In our experiments, when soil pH is lower than 4.0 but the Al/Ca mol ratio was not high enough, root growth of *C. lanceolata* and *S. superba* was not adversely affected.

CONCLUSIONS

As shown in the discussions, the effects of acidic precipitation and soil acidification on the roots of *C. lanceolata* and *S. superba* may be concluded as follows:

1. When soil pH was already lower than 4.0 and the precipitation of pH 3.0 continued, both *C. lanceolata* and *S. superba* saplings were not made dead. What is interesting was that the root growth of both species had somewhat increase. It may be brought about by fertilization effect of NO_3^- in the simulated acid rain (Bledose, 1983).

2. When the Al/Ca mol ratios in soils and roots attained 5 just at the same time, root

biomass production of *C. lanceolata* was statistically prominently inhibited (T-test). And for *S. superba*, when the Al/Ca mol ratios in soils and roots respectively were 16 and 3 approximately, the root biomass production was not affected markedly.

3. When soil acidity increased from pH 5.12 to pH 3.35 and artificial precipitation pH declined from pH 4.5 to pH 2.0, the fine root elongation of *C. lanceolata* was inhibited obviously. For *S. superba*, when soil and precipitation acidity decreased respectively by 0.94 and 2 units, the fine root elongation was not adversely affected.

4. When "rain" acidity increased from pH 4.5 to pH 2.0, Al concentrations increased from 0.26 to 0.91 mmol per 100g dry soil in top soil with the Al/Ca mol ratio from 0.1 to 4, and in rhizosphere soil from 0.3 to 1.5 mmol per 100g dry soil with the Al/Ca mol ratio from 0.2 to 15.

5. Increased acidity of simulated acid rain increased the leaching of Ca, Mg and other cations.

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